REMARKS

Claims 1 to 15 are all the claims pending in the application, prior to the present amendment.

Applicants filed an Information Disclosure Statement with a Modified PTO/SB/08 A & B form on March 21, 2005 listing various documents. The Examiner has not retuned to applicants a signed and dated copy of this form. Applicants request the Examiner to return to applicants a signed and dated copy of this form to indicate that the Examiner has considered and made of record the documents listed on the form.

The Examiner has acknowledged applicants' claim for priority. The Examiner, in the Office Action Summary, has checked the boxes 12) and a), but has not checked any of the boxes "1.," "2." or "3." Applicants request the Examiner to check the appropriate box.

The Examiner has objected to claims 3 and 4 because the number which is used to identify the "growth crucible" in the drawing is not correctly shown in the claims.

In response, applicants have amended the claims to delete the reference numerals.

Claims 1 and 15 have been rejected under 35 U.S.C. § 103(a) as obvious over U.S. Patent 4,866,005 to Davis et al in view of U.S. Patent 3,275,415 to Hung Chi Chang et al.

In addition, claim 2 has been rejected under 35 U.S.C. § 103(a) as obvious over Davis et al and Chang et al in view of U.S. Patent 6,193,797 to Shiomi et al.

Applicants submit that Davis et al, Chang et al and Shiomi et al do not disclose or render obvious the subject matter of claims 1 and 15 and, accordingly, request withdrawal of these rejections.

Applicants have amended independent claims 1 and 13 to incorporate recitations from claim 2 and from the description at page 15, lines 15-27 of the specification. Support for amended claim 13 can also be found at page 21, line 23 to page 22, line 2 of the specification.

In addition, applicants have canceled claims 4 and 14, and have amended the dependencies of various claims where appropriate. Applicants have added new claim 16 that contains recitations that were removed from claim 13, and have added new claims 17 and 18 that depend from claim 16 or 17 and which contain recitations from claims 14 and 15.

As will be understood from the amended claims, the method and apparatus of the present invention for producing a silicon carbide single crystal have the features and effects as shown hereinafter.

In the present invention, the atmosphere gas that surrounds the growth crucible contains a silicon gas, and the vapor pressure of the silicon gas that surrounds the growth crucible is continuously maintained to be higher than that of the silicon gas in the gas sublimated from the silicon carbide raw material in the growth crucible and the vapor pressure of the silicon gas in the growth crucible is maintained substantially equal to or higher than equilibrium vapor pressure of the silicon gas contained in the sublimated gas.

Since the growth crucible formed of graphite exhibits no hermeticty against gas at a high temperature in the neighborhood of 2,000°C, the silicon gas surrounding the growth crucible

permeates the growth crucible wall of graphite and diffuses inside the growth crucible. See page 16, lines 8-17 of the specification. Therefore, the vapor pressure of the silicon gas in the growth crucible is continuously maintained to be substantially equal to or higher than equilibrium vapor pressure of the silicon gas contained in the sublimated gas.

As described at page 24, lines 21-26 of the specification, it has been known that when crystal growth of a compound semiconductor is performed, in order to maintain constant the stoichiometric composition of elements constituting the crystal, it is effective to maintain the vapor pressure of the constituent element of high dissociation pressure at a high level during the crystal growth.

Also, as described at page 24, line 27 to page 25, line 8 of the specification, when the crystal growth is performed, if the vapor pressures of the constituent elements are equal to one another, the amount of the element of high dissociation pressure contained in the growth crystal is lowered, leading to generation of vacancies in the crystal and occurrence of minute lattice strain associated with generation of the vacancies and, as a result, there is a high likelihood that such crystal defects induce dislocations and stacking faults in the grown crystal.

In the silicon carbide single crystal growth, silicon corresponds to the constituent element of high dissociation pressure. See page 25, lines 9-11 of the specification. In the present invention, therefore, silicon of high dissociation pressure diffuses from the outside of the growth crucible through the crucible wall into the crucible, thereby causing the vapor pressure of the silicon gas in the growth crucible to become equal to or higher than the equilibrium vapor pressure of the sublimated gas. See page 25, lines 12-20 of the specification.

With the aforementioned configuration adopted in the present invention, generation of crystal defects, which is associated with silicon carbide single crystal growth by means of the conventional sublimation process, can considerably be suppressed. See page 25, lines 20-24 and page 32, lines 6-21 of the specification.

Turning now to the Examiner's detailed statements of the above rejections, they are quite lengthy and mostly involves quotations of various passages from the references. The Examiner identifies these passages by referring to the column number and line number of each reference from which he takes the quote.

In essence, the Examiner takes the position that Davis et al disclose all of the recitations of claims 1 and 15, except that Davis et al do not disclose surrounding a silicon gas around the growth crucible.

The Examiner relies on Chang et al for a disclosure of surrounding a growth crucible with a silicon gas, and argues that it would have been obvious to surround the growth crucible of Davis et al with the silicon gas of Chang et al in order to reduce the amount of defects in SiC single crystals.

With respect to claim 2, the Examiner states that Davis et al and Chang et al render obvious the present invention, but do not teach that the silicon carbide singe crystal is grown with vapor pressure of the silicon gas in the growth crucible maintained substantially equal to or higher than equilibrium vapor pressure of silicon gas in the gas sublimated from the silicon carbide raw material.

The Examiner relies on Shiomi et al for a teaching of having the vapor pressure of Si higher than that of SiC_2 or Si_2C during the generation of SiC. The Examiner argues that it would have been obvious to set the vapor pressure of the silicon gas in the growth crucible of Davis et al and Chang et al to maintain substantially equal to or higher than the equilibrium vapor pressure of the silicon gas in the gas sublimated from the silicon carbide raw material in the growth crucible, as suggested by Shiomi et al.

Applicants disagree with the Examiner's characterization of the teachings of these references and disagree with his conclusion concerning obviousness.

At page 4 of the Office Action, the Examiner states that Davis et al, at column 11, lines 23-30, teaches "an apparatus for the preparation of relatively large single crystals of a decomposing compound, in combination, a casing containing a charge for producing vapors of the compound, heating means for heating the charge to a temperature at which vapors of the compound are evolved, a small empty hollow member having closed ends disposed in the charge so that the said vapors contact the walls of the hollow member having a porosity to admit passage of predetermined amounts of said vapors into the hollow."

The Examiner further states, at page 4 of the Office Action, that Davis et al disclose, at column 11, lines 43-46, the recitation "wherein the hollow member comprises a hollow cylinder of graphite with graphite end disks, and the charge produces vapors of silicon carbide."

These passages, however, do not appear in Davis et al, but rather appear in Chang et al.

In any event, the Examiner does not clearly identify the passage(s) in Chang et al upon which he is relying for a teaching of surrounding a growth crucible with silicon gas.

Chang et al disclose a thin walled hollow cylinder 14 having porous walls which is disposed in a container 18 as shown in Figures 1, 2 and 3. Single crystals are grown on the inside wall of the cylinder 14.

In the passage at column 8, lines 53-67 that is quoted by the Examiner, spots or strip films of silicon are painted on the inside wall of cylinder 14 to provide high local concentrations of silicon, so that silicon carbide vapor concentrations develop at these sites and crystals are nucleated there preferentially to other areas on the surface where no such silicon concentration is present. The silicon eventually vaporizes completely during the process.

This vaporization of silicon creates silicon gas inside the hollow cylinder, and the silicon gas does not surround the cylinder. Thus, this passage of Chang et al does not support the Examiner's assertion that Chang et al disclose a surrounding of a silicon gas around the growth crucible.

Further, in the present invention, a silicon carbide single crystal is grown on a seed crystal substrate formed of a silicon carbide single crystal through crystallization of a gas sublimated from the silicon carbide raw material on the substrate. Thus, in the present invention, no silicon spot is disposed on the inside surface of the growth crucible.

Chang et al also disclose at column 3, lines 20-39, that a mass 16 forming charge of raw materials surrounds the cylinder 14. Chang et al state that this charge can be made from silicon carbide particles, such as commercial silicon carbide crystals, or a mixture of elemental silicon

and carbon, or both. This passage states that elemental silicon and carbon may be used in place of silicon carbide as a source of vapor. Chang et al state that the silicon and carbon will react to provide silicon carbide prior to reaching operating temperatures and, consequently, vapors of silicon carbide will be evolved from the mass 16.

It appears to applicants that the Examiner may be interpreting this embodiment of Chang et al as teaching a vapor of silicon as a gas surrounding the growth cylinder. However, in the present invention, there is a source of silicon carbide inside the growth crucible and a silicon gas outside the growth crucible. Thus, in the present invention, the charge of raw material for forming the silicon carbide is inside the growth cylinder, and there is a silicon gas outside. In contrast, in this embodiment of Chang et al there is only a charge of raw material that is outside of the growth cylinder. This charge of raw material forms a gas which permeates the walls of the cylinder. In this embodiment of Chang et al, there is not a separate charge of raw material inside the cylinder and a surrounding gas outside the cylinder.

Chang et al further describe at column 3, lines 20-27 that the periphery of the hollow cylinder 14 shown in Fig. 1 should be packed with raw material mass as densely as possible.

On the other hand, in the present invention, it is necessary to appropriately determine the pressure of the atmosphere gas surrounding the growth crucible in order to optimize the growth rate and crystallinity of the silicon carbide single crystal. See page 22, lines 8-12 of the specification. Chang et al do not disclose or suggest this concept.

In Davis et al, there is only a charge of raw material forming silicon carbide inside the growth cylinder.

Davis et al show two different embodiments of their apparatus.

In one embodiment, shown in Figure 1, there is an annular chamber 16 that contains a silicon carbide source powder which when heated provides silicon carbide vapor that passes through porous graphite liner 11 into the central sublimation chamber 20 where it grows on seed crystals 17.

If one of ordinary skill in the art were to combine these teachings of Davis et al with Chang et al, one might be led to employing separate sources of silicon and carbon in the annular chamber 16. Such a modification, however, still would not result in the present invention.

Similarly, in the embodiment shown in Figure 3 of Davis et al, a silicon carbide source powder 40 is held in a bed 41, and when heated, the silicon carbide vapor passes through a porous graphite barrier 37 where it grows on seed crystals 32. If one of ordinary skill in the art were to combine these teachings of Davis et al and Chang et al, one might be led to employing a separate silicon source and a separate carbon source in the bed 41. Such a modification, however, still would not result in the method of the present invention.

Shiomi et al do not supply the above-discussed deficiencies of Davis et al and Chang et al.

Although the Examiner relies on Shiomi et al for a suggestion of having a higher pressure for the silicon vapor in the growth crucible, the present specification, at page 15, discloses that the vapor pressure of the silicon gas surrounding the growth crucible is higher than the vapor pressure of the silicon gas contained in the sublimate gas in the growth crucible. Page 16

discloses that the crucible-surrounding silicon gas pressure is maintained so that the crucible-surrounding silicon gas pressure is higher than the equilibrium vapor pressure. Claim 1 as amended above recites the silicon gas pressure in the atmosphere gas that surrounds the growth crucible. This is not disclosed or suggested in Shiomi et al.

In Shiomi et al, solid Si is evaporated when being heated to the first temperature area Ti and, since the temperature of the first temperature area Ti is regulated, the partial pressure of Si can be adjusted and, in addition, the evaporated Si is reacted with carbon to generate an SiC-forming gas. See column 3, lines 11-17. Further, it is described at column 5, lines 19-23 that if the partial pressure of carbon to combine with the evaporated Si is made substantially the same as the partial pressure of Si determined by the temperature of the first temperature area Ti, a high-quality SiC single crystal can be obtained.

As stated above, however, when the crystal growth is performed, if the vapor pressures of the constituent elements are equal to one another, the amount of the element of high dissociation pressure contained in the growth crystal is lowered, leading to the inducing of dislocations and stacking faults in the grown crystal. See page 24, line 27 to page 25, line 8 of the specification.

For this reason, in the present invention, the vapor pressure of the silicon gas in the growth crucible is made equal to or higher than the equilibrium vapor pressure of the sublimated gas. See page 25, lines 12-20 of the specification.

Based on amended claims 1 and 13, applicants submit that none of Davis et al, Chang et al and Shiomi et al discloses the configuration in which the silicon carbide single crystal is grown, with the atmosphere gas that surrounds the growth crucible containing a silicon gas and

with vapor pressure of the silicon gas that surrounds the growth crucible continuously maintained to be higher than that of the silicon gas in the gas sublimated from the silicon carbide raw material in the growth crucible and that in the growth crucible maintained substantially equal to or higher than equilibrium vapor pressure of the silicon gas contained in the sublimated gas.

As is clear from the above, the method for controlling the vapor pressure of the silicon gas in the present invention quite differs from the control method of Shiomi et al and is not described in either Davis et al or Chang et al. Therefore, the present invention is not obvious to those skilled in the art from any of these documents.

With respect to claim 15, it depends from claim 13. Claim 13 was not included in the above rejections, but was included in a separate obviousness rejection over additional prior art that applicants discuss below. Since the Examiner apparently recognizes that Davis et al, Chang et al and Shiomi et al do not render obvious the recitations of claim 13, it follows that they do not render obvious the recitations of claim 15 which include the recitations of claim 13.

In view of the above, applicants submit that the subject matter of the present claims is patentable over the cited documents and, accordingly, request withdrawal of these rejections.

Claims 3-5, 7-10 and 12-14 have been rejected under 35 U.S.C. § 103(a) as obvious over Davis et al and Chang et al in view of U.S. Patent Publication 2001/0004877 to Shigeto et al.

Applicants submit that these documents do not disclose or render obvious the subject matter of the present claims and, accordingly, request withdrawal of this rejection.

The Examiner states that Davis et al and Chang et al do not teach continuously feeding a silicon raw material "from outside into the space" and also evaporating the silicon raw material.

The Examiner states that they also do not teach that the silicon raw material feed rate and the amount of atmosphere gas pressure surrounding the growth crucible of SiC.

The Examiner argues that Shigeto et al '877 suggest employing a continuous feeding stage of silicon raw material from outside into the space between the outer and growth crucible in a SiC production method and, therefore, it would have been obvious to employ such a technique in Davis et al and Chang et al.

However, Shigeto et al '877 do not disclose a method of feeding a silicon raw material from outside into a space between an outer crucible where silicon vapor is present in a surrounding gas atmosphere and a growth crucible where silicon carbide is grown.

The Examiner refers to Paragraphs [0003], [0017], [0018], [0021], [0032] and [0052] of Shigeto et al '877, but none of these paragraphs and none of the drawing figures in Shigeto et al '877 show an outer surrounding crucible having silicon vapor and a growth crucible where silicon carbide is grown.

Further, with respect to claims 9 and 10, Shigeto et al describe in paragraph [0052] that the total pressure is set preferably within the range of (1 to 300) x 133 Pa to generate reactive gas. Shigeto et al '877 also describe in paragraph [0059] that argon was introduced into the production apparatus 51 shown in Fig. 1 and that crystal growth is conducted by setting argon atmosphere to a pressure of 50 x 133 Pa.

However, Shigeto et al '877 do not disclose that the gas surrounding the reaction crucible is composed of Si gas.

Moreover, Shigeto et al '877 do not describe that the silicon carbide single crystal is grown, with the vapor pressure of the silicon gas that surrounds the growth crucible continuously maintained to be higher than that of the silicon gas in the gas sublimated from the silicon carbide raw material in the growth crucible and with the vapor pressure of the silicon gas in the growth crucible maintained substantially equal to or higher than equilibrium vapor pressure of the silicon gas contained in the sublimated gas.

Accordingly, applicants submit that Shigeto et al '877 do not supply the deficiencies of Davis et al and Chang et al.

In view of the above, applicants submit that the present claims are patentable over Davis et al, Chang et al and Shigeto et al '877 and, accordingly, request withdrawal of this rejection.

Claim 6 has been rejected under 35 U.S.C. § 103(a) as obvious over Davis et al and Chang et al in view of U.S. Patent 6,406,539 to Shigeto et al.

The Examiner states that Davis et al and Chang et al disclose all of the recitations of claim 6, but do not teach that the silicon raw material fed from outside into the space in solid form has powder particles having a diameter of 0.2 to 5 mm. The Examiner relies on Shigeto et al '539 for a teaching of carbon granules having a grain size of 100 μm to 5 mm.

Claim 6 depends ultimately from claim 1. Shigeto et al '539 do not supply the deficiencies of Davis et al and Chang et al with respect to the recitations of claim 1 and, accordingly, do not render obvious the recitations of claim 6.

Further, the grain size recitations in Shigeto et al '539 relate to the carbon granule and not to the silicon raw material. Shigeto et al '539 do not disclose any information about the size of the silicon raw material. Accordingly, Shigeto et al '539 do not supply the deficiencies of Chang et al and Davis et al.

In view of the above, applicants submit that claim 6 is patentable over Davis et al, Chang et al and Shigeto et al '539 and, accordingly, request withdrawal of this rejection.

Claim 11 has been rejected under 35 U.S.C. § 103(a) as obvious over Davis et al, Chang et al, Shigeto et al '877 and further in view of U.S. Patent 6,428,621 to Vodakov et al.

The Examiner relies on Vodakov et al for a teaching of a growth rate of a silicon carbide single crystal of 1 mm/hour or more, as set forth at column 8, lines 42-46.

Claim 11 is a dependent claim that depends ultimately from claim 1. Vodakov et al do not supply the deficiencies of Davis et al, Chang et al and Shigeto et al '877 with respect to claim 1.

Accordingly, applicants submit that claim 11 is patentable over the cited documents and, therefore, request withdrawal of this rejection.

In view of the above, reconsideration and allowance of this application are now believed to be in order, and such actions are hereby solicited. If any points remain in issue which the Examiner feels may be best resolved through a personal or telephone interview, the Examiner is kindly requested to contact the undersigned at the telephone number listed below.

The USPTO is directed and authorized to charge all required fees, except for the Issue Fee and the Publication Fee, to Deposit Account No. 19-4880. Please also credit any overpayments to said Deposit Account.

Respectfully submitted,

Sheldon I. Landsman

SUGHRUE MION, PLLC
Telephone: (202) 293-7060
Facsimile: (202) 293-7860
WASHINGTON OFFICE
23373
CUSTOMER NUMBER

Sheldon I. Landsman
Registration No. 25,430

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